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The dual effect of vegetation green-up date and strong wind on the return period of spring dust storms

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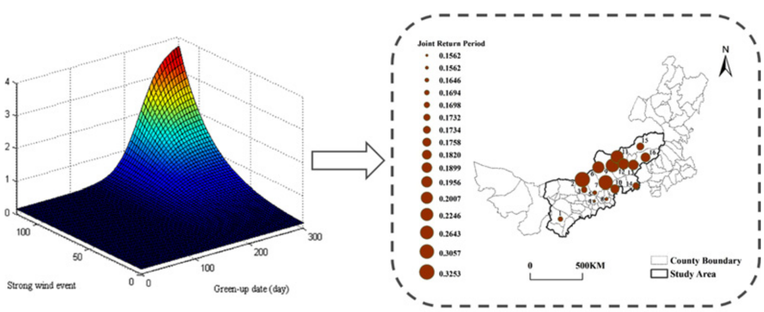
HIGHLIGHTS

- The bivariate Copula model is developed using both geographical and meteorological factors for evaluating dust storm return period.
- The simulated joint return periods are closer to the reality by introducing the green-up date variable.
- Copula method was used to identify the disaster high risk area.

GRAPHICAL ABSTRACT



Joint return period

Risk map

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ABSTRACT

Vegetation phenology changes have been widely applied in the disaster risk assessments of the spring dust storms, and vegetation green-up date shifts have a strong influence on dust storms. However, the effect of earlier vegetation green-up dates due to climate warming on the evaluation of dust storms return periods remains an important, but poorly understood issue. In this study, we evaluate the spring dust storm return period (February to June) in Inner Mongolia, Northern China, using 165 observations of severe spring dust storm events from 16 weather stations, and regional vegetation green-up dates as an integrated factor from NDVI (Normalized Difference Vegetation Index), covering a period from 1982 to 2007, by building the bivariate Copula model. We found that the joint return period showed better fitting results than without considering the integrated factor when the actual dust storm return period is longer than 2 years. Also, for extremely severe dust storm events, the gap between simulation result and actual return period can be narrowed up to 0.4888 years by using integrated factor. Furthermore, the risk map based on the return period results shows that the Mandula, Zhurihe, Sunitezuoqi, Narenbaolige stations are identified as high risk areas. In this study area, land surface is extensively covered by grasses and shrubs, vegetation green-up date can play a significant role in restraining spring dust storm outbreaks. Therefore, we suggest that Copula method can become a useful tool for joint return period evaluation and risk analysis of severe dust storms.

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1. Introduction

Return period is an indicator for expressing the possibility of disaster occurrence. It usually refers to a relatively stable period of event occurrence that exceeds an intensity threshold over a long period, and is an important parameter in describing events such as disasters (Li et al., 2015a, 2015b; Liu et al., 2015). Return period can be used to describe the severity and frequency of disasters. In meteorological or hydrological fields, the return period is often expressed through terms such as "once in 50 years" and "once in a century."

Analyses of the frequency of natural disasters can reveal their properties, such as the occurrence regularity, and have important practical significance in risk assessment and management, and in comprehensive exploitation and utilization of resources. Return periods have become a research focus in natural disaster frequency analyses, and have been widely applied in disaster risk assessments in meteorological or hydrological fields, as well as in the planning, design, operation, and management of projects (Bonaccorso et al., 2003; Fernández et al., 2012; Iqbal and Ali, 2013; Liu et al., 2012). Studies of return periods may help government sectors to enact disaster prevention and mitigation measures, and to make related development policies (De Silva et al., 2015); engineering departments to design projects standards (De Biagi et al., 2016; Shiau, 2003; Sindhu and Unnikrishnan, 2012); insurance companies to make decisions on insurance and investment (Mochizuki et al., 2015); and the public to easily understand disaster risks and thus to consciously avoid them (Su et al., 2015). Therefore, the accuracy of return period evaluations is extremely important. The overestimation or underestimation of return periods may affect the evaluation and management of disaster risks. When the scale of a natural disaster is determined, overestimation of the return period may lead to higher design standards and increased spending on disaster prevention and reduction, which may result in unnecessary human and financial resource waste. More serious effects come from underestimation of the real return period. If the occurrence of disasters in reality is more frequent than that of the estimation, it may lead to serious damage and losses caused by insufficient design standards or lack of attention and investment. For example, a rare snow disaster occurred in south China in January 2008, and scholars believed that the return period of the event was 50–100 years (Ye, 2014). However, in January 2016, a more serious cold spell and snow disaster occurred again in south China, with the most southerly snow line in recorded history, and 76 meteorological stations recorded the lowest temperatures in their operational history. Many parts of south China suffered from quick freezing caused by the most extreme cold wave in 2016. Owing to a lack of emergency preparedness, the disaster caused a loss of more than a hundred million Yuan. Hence, the losses caused by the underestimation of the forecast return period were very significant.

Dust storms are one of the major natural disasters in northern China, which are expected to continue to occur frequently because of global warming and deteriorating vegetation coverage (He et al., 2015), and Inner Mongolia, in particular, experiences extremely serious dust storms, especially the frequently occurring spring dust storms (Du et al., 2014). Dust storms can cause serious losses and harm to both economic development and peoples' lives and property. Therefore, employing effective methods to analyze the return period of dust storms, grasping the occurrence law of disasters, objectively and quantitatively evaluating disaster strength, and properly designing return period standards can effectively identify risk areas and levels, and can provide guidance for the management of disaster risks.

To improve the capacity for predicting dust storm return periods, it is necessary to understand the complexity of its occurrence process. This study shows that the influencing factors for dust storms are not unitary, so data inferences based on traditional single variable methods cannot accurately forecast actual disaster occurrence trends, and may

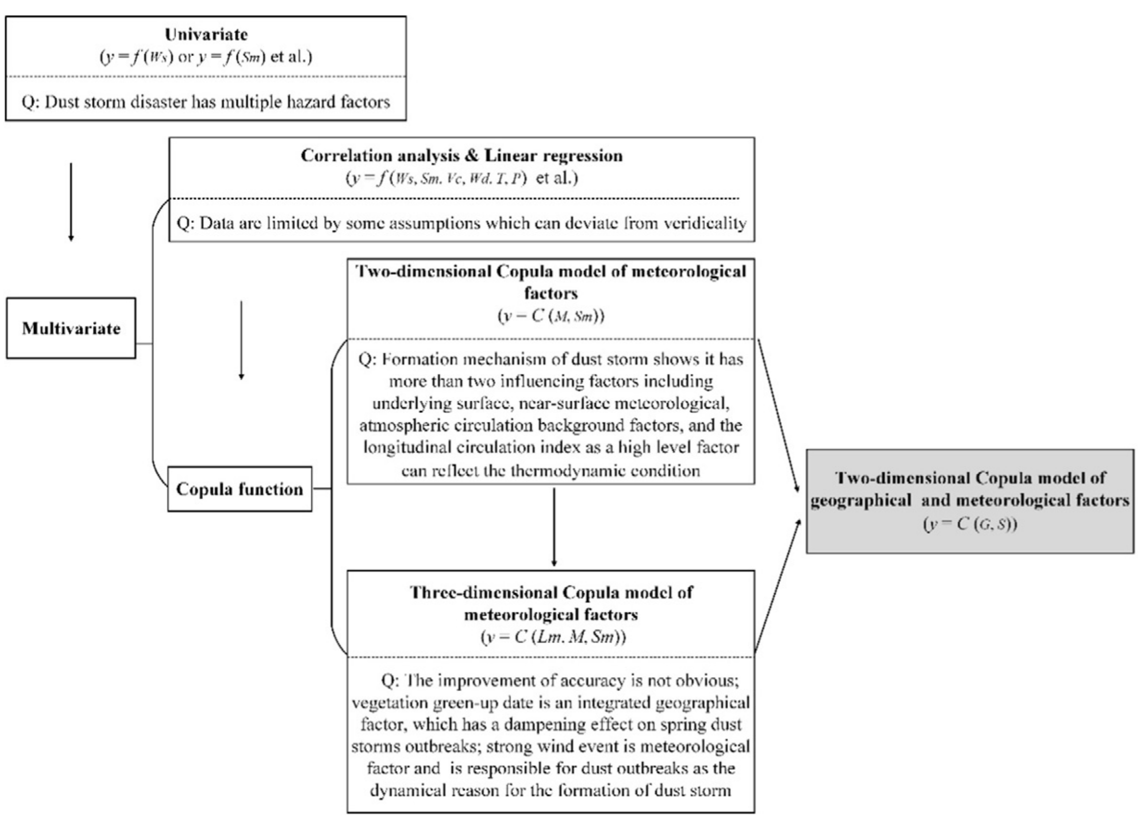

Fig. 1. Development process for the return period analysis research of dust storm. The arrow represents method improvement path; the boldface in the solid-line rectangles represents the research method, with the factors and functional expression in parentheses and the existing problems below the dashed-line; the gray rectangle indicates the method in this paper. Ws: Wind speed; Sm: Soil moisture; Vc: Vegetation coverage; Wd: Windy days; T: Temperature; P: Precipitation; M: Maximum wind speed; D: Duration; Lm: Longitudinal circulation index; G: Vegetation green-up date; S: Strong wind event.

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